# Can I Wash It? : The Effect of Washing Conductive Materials Used in Making Textile Based Wearable Electronic Interfaces.

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## ABSTRACT
In this paper we explore the wash-ability of conductive materials commonly use in creating traces and touch sensors in wearable electronic textile systems. We performed a wash test measuring change in resistivity of conductive traces constructed using different combinations of conductive materials after each wash cycle.

## Author Keywords
Electronic Textile Wash Test, Conductive Materials Wash Test.

## ACM Classification Keywords
H5.m. Information interfaces and presentation (e.g., HCI): Miscellaneous.

## General Terms
Design, Experimentation, Performance, Reliability.

## INTRODUCTION
Since the beginning of wearable computing and technology embedded clothing, one question that consistently is asked of designers and researchers is "ok that's cool, but can I wash it?". In developing wearable computers and functional clothing the notion of wash-ability is complex. For example, in Post's Jacket with a capacitive fabric keyboard [17] we can ask the question of wash-ability across a number of different components. Is the micro-controller washable? Is the circuit board washable? Are the wires washable? Is the embroidery washable? Is the denim jacket itself washable? Are the connections between the components washable? When these different components are washed what happens to them, how do they change and does the device still work at an acceptable level after the washing? This paper focuses on the wash-ability of some conductive materials commonly used in making textile based electrical traces and capacitive touch sensitive interfaces.

The importance of the wash-ability of wearables, is impart due to the advent of washing technology itself. Gram-Hanssen explains in a paper about consuming technologies and developing routines "women from the 1920's and 30's described how their washing routines changed almost immediately upon acquiring a washing machine [13] from collecting clothes for a monthly washing to washing more often and much more." [10]. If wearable electronics were to make it to the consumer market, and were to be sold as garments, it is also important to note that federal regulations require specific care instructions [4,5] especially for clothes, which have to be cleaned in a specific way.

Many of the components used in creating embedded textile technologies can be taken off of the garment before washing; this might include the microprocessor and circuit board. Another way to improve the wash-ability of a garment would be to encapsulate these components, which are very sensitive to water. Buechley's work in electronic textiles construction kits has lead to the Arduino Lillypad and has at least started to answer the question of wash-ability of circuit boards and microprocessors [2,3]. However, the conductive traces and materials used in the garments are attached or sewn to the garment in such a way as they become part of the fabric of the garment. How these conductive materials change during washing matter because they are used to power sensors, are used to create sensors [9,11,19], are used in collecting energy in electrostatic harvesting [18], and can be used to even carry information [14]. An increase in resistance of conductive materials within a wearable electronic garment due to the ordinary household's washing and cleaning processes could greatly reduce the garment's ability to function properly as an electronic device.

## PROCEDURE
There are many ways to wash clothes. For the purpose of our testing we decided to use a standard upright agitator washing machine GE Spacemaker Model WSM2700HAWWW and a standard detergent. 1 ounce of All 2x Ultra detergent is used each wash cycle. Lee et all explains the difficult nature of the mechanical washing actions [12], however by using the same water fill level and same cycle time we tried to standardize the mechanical aspects of the washing cycle as much as possible.


**Figure 1 Washing Machine setting and Detergent used in washing cycles.**

All washes were made in warm water, at medium load, and a regular wash cycle (11). We chose to wash on the warm cycle because we wanted to use a harsher condition, hoping that if the conductive materials held up during a warm wash cycle they would be more likely to hold up during a cold wash cycle. We also chose the regular agitation and wash cycle because these would be harsher conditions than a gentle cycle.

We chose 2 types of conductive thread to test; the first is a coated conductive thread [6]. The Shieldtex size 33 thread is completely conductive on the outside surface of the thread, and is very useful when embroidering interfaces [9,19] because as the thread sews over itself it increases the conductive surface and lowers electrical resistance. One downside to the Shieldtex size 33 thread is that the conductive coating on the thread makes it hard to regulate the tension of sewing and embroidery machines properly, and is more difficult to use within industrial machines when working at industrial speeds. We also chose to test Shieldtex's size 40 thread [7], which is a ply yarn consisting of both conductive and nonconductive polyester. The advantage of the Shieldtex size 40 yarn is that it runs much better through sewing and embroidery machines, but it can not be sewn over itself to reduce resistance.

We were also interested in the resiliency of conductive screen-printed interfaces to washing. We chose a conductive ink which promised to have some flexibility durability when printed on a flexible solid (not fabric woven) polyester, polyamide or other substrates [1].

Because we wanted to test on a substrate, which would be close to a worst-case scenario for building electronic textiles, but commonplace in garment production we chose to sew and print our conductive materials onto thick twill weave cotton drill. Cotton fibers swell and enlarge as they absorb water, and shrink as they dry. Cotton fabric also has a tendency to shrink, the fabric that we used was preshrunk, but minimal shrinking can still occur over wash cycles. Shrinkage is important because if the substrate does not shrink at the same rate as the print or thread then durability issues can result. A twill weave was chosen because of its ubiquitous use in the apparel industry, however twill weaves are also more flexible than plain weave fabrics due to fewer interlacing between the warp and weft yarns. The added flexibility of the twill weaves also means that this fabric type is harsher on the conductive materials.

As our parallel also wished to explore how to best combine conductive ink and conductive embroidery to create the most robust interfaces, we also wanted to see the effects of washing on combinations of conductive materials.

Specifically, we examine the following 12 test conditions:

**Less Conductive Thread (Shieldex size 40 22/7 PET sewing thread)**

1. Single trace*

2. Double trace**

3. Single trace under conductive ink (sewn first and ink printed on top of trace and then cured)

4. Single trace on top of conductive ink (ink printed first and thread sewn on top of cured ink)

5. Double trace under conductive ink

**More Conductive Thread (Shieldex size 33 117/17 sewing thread)**

6. Single trace

7. Double trace

8. Single trace under conductive ink

9. Single trace on top of conductive ink

10. Double trace under conductive ink

Conductive Ink

11. Ink alone

12. Ink covered with Plastisol***

* Single trace = A single straight sewn line of thread

** Double trace = A single straight sewn line of thread double back over itself

*** Plastisol Ink is a standard type of screen printing ink. It is a pigment suspended in a binder which cures into a plastic after being heated.

In creating the single and double traces for our test we utilized a CAD program and a Meistergram 1501 commercial embroidery machine. This assured that each trace was the same number of stitches and length so they could be compared effectively to each other across conditions and trials.

| A | B | C | D | E | F | G | H | I | J |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2 | 3&4 | 5 | 6&7 | 8 | 9 | 10 | 11 | 12 |
| 2 | 3&4 | 5 | 6&7 | 8 | 9 | 10 | 11 | 12 | 1 |
| 3&4 | 5 | 6&7 | 8 | 9 | 10 | 11 | 12 | 1 | 2 |
| 5 | 6&7 | 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3&4 |
| 6&7 | 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3&4 | 5 |
| 8 | 9 | 10 | 11 | 12 | 1 | 2 | 3&4 | 5 | 6&7 |
| 9 | 10 | 11 | 12 | 1 | 2 | 3&4 | 5 | 6&7 | 8 |
| 10 | 11 | 12 | 1 | 2 | 3&4 | 5 | 6&7 | 8 | 9 |
| 11 | 12 | 1 | 2 | 3&4 | 5 | 6&7 | 8 | 9 | 10 |
| 12 | 1 | 2 | 3&4 | 5 | 6&7 | 8 | 9 | 10 | 11 |

**Table 1 Order of test conditions in sample books.**

We created 10 books of cotton swatches each containing 1 the 12 test conditions arranged in a Latin square with conditions 3 & 4 and 6 & 7 each sharing a swatch (see Table 1). Because the swatches facing the outside might receive less or more abrasion from the washing cycle the completed swatch books A-J were constructed to minimize any order effect from the placement of the swatch in the stack.

The completed swatches were also designed to be long and thin and sewn together at the thin side so that the seam or spine of the attachment did not shield the swatches from the agitation of the washing cycle.

**Figure 2 conductive material swatch sample book construction.**

The swatches were washed together for each wash cycle, and were hung to air dry on a metal rack. The swatches were measured for resistance prior to their first wash and then after every subsiquint wash once they were dry. All measurements were conducted using a Fluke 73 III Multimeter.

**Figure 3 Swatch sample books hanging to air dry.**

## RESULTS

The results will be given for each test condition. The swatches were washed for 6 wash cycles. The graphs included in this results section show the resistance change over the 6 wash cycles.

### Test Conditions 1&2 Less conductive thread single and double trace.

The less conductive thread had only three conductive fibers out of thirty. While it was easier to work, it proved to be more fragile. Most swatches failed after three wash cycles.

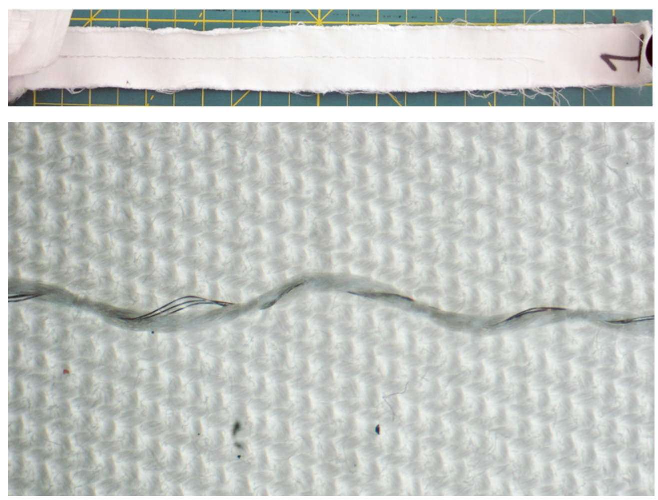
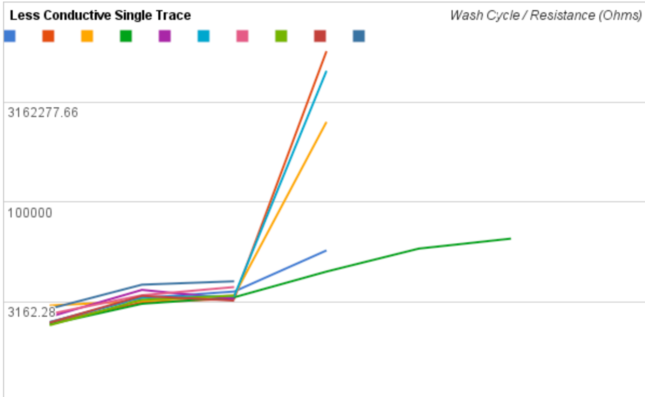
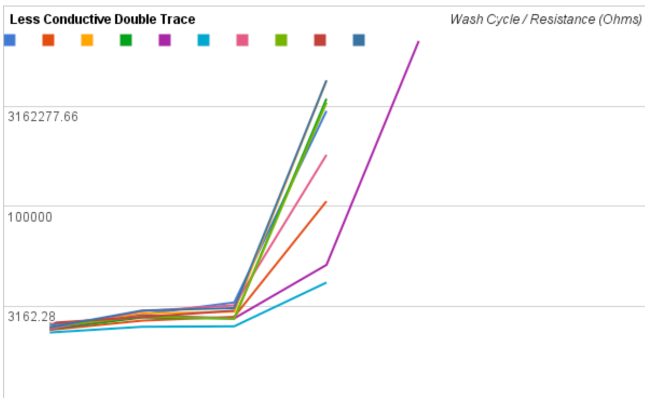


**Figure 4 Swatch B1 less conductive thread single trace**




**Graph 1**




**Graph 2**

## Test Conditions 3&4 Less conductive thread single trace sewn under conductive ink and sewn over conductive ink.

As expected the single trace held up better with the combination of ink and trace. Also as expected the trace held up better when the ink was printed on top of the trace and cured, allowing the ink to fill in the fibers of the trace and sewing puncture holes in the fabric with conductive material.

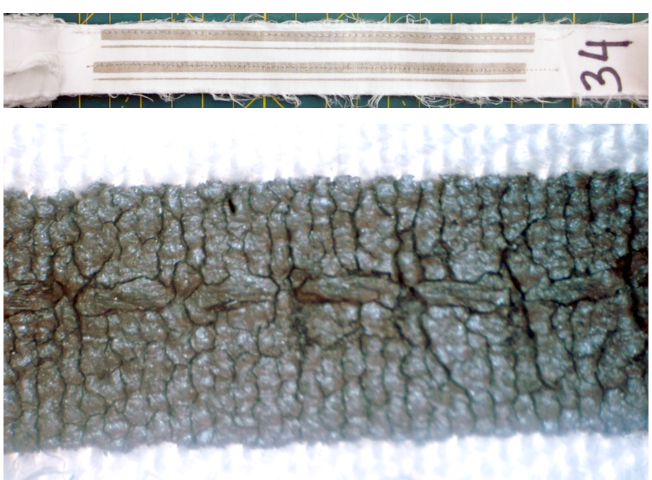



**Figure 5 Swatch B3 less conductive thread single trace under conductive ink**

When the ink is printed on top of the thread, it saturates the thread and creates a better connection.

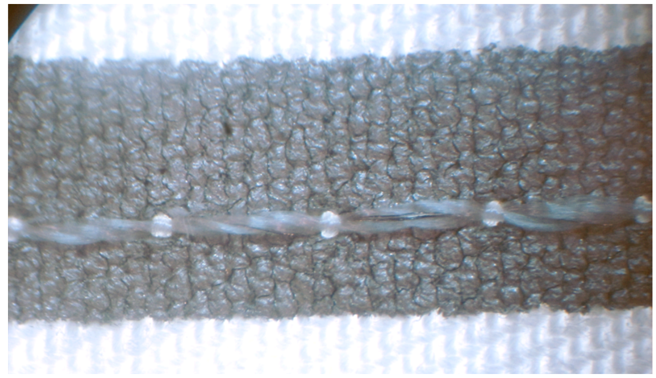
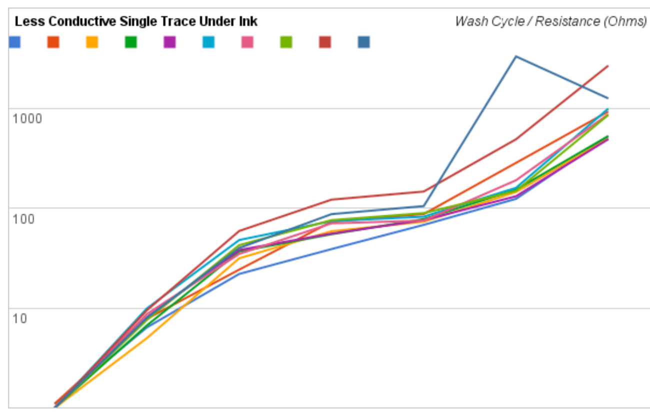
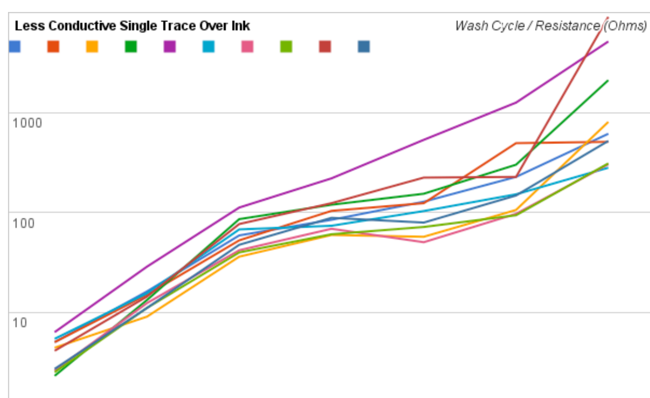


**Figure 6 Swatch B4 less conductive thread single trace over conductive ink**

However, when the thread is stitched on top of the conductive ink, it creates a poorer contact. It also abrades the conductive ink when the machine punctures the fabric to sew on the thread.




**Graph 3**




**Graph 4**

## Test Condition 5 Less conductive thread double trace sewn under conductive ink.

The double trace provides even more contact with the ink. However, in some instances the ink flakes off with washing.

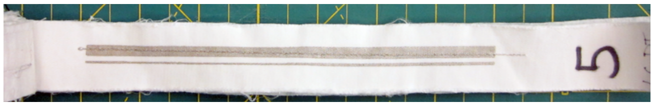
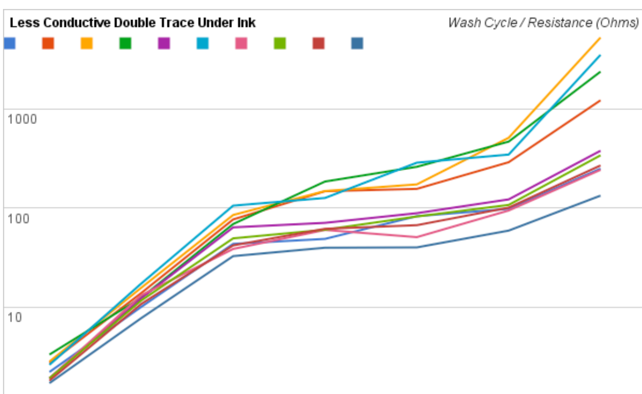


**Figure 6 Swatch B5 less conductive thread double trace under conductive ink**

Because of the thickness of the double trace, it may have been harder for the ink to completely penetrate the fabric from the screen-printing process. This would happen at the puncture sites creating during the sewing process, because they are the lowest portion of the fabric plane and are relatively close to the highest point on the surface of the fabric (the top of the double trace).




**Graph 5**

## Test Conditions 6&7 Fully conductive thread single and double trace.

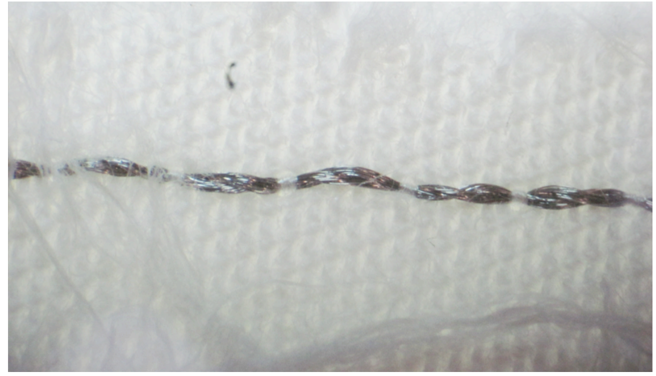


**Figure 7 Swatch B6 more conductive thread single trace**

The more conductive thread contained more conductive material and tended to survive all six washings. Due to the nature of how the thread was made by coating the outside surface of the thread, if one side of the conductive material failed (say the outside cracked or shorted due to washing abrasion), the other side still had the ability to conduct.

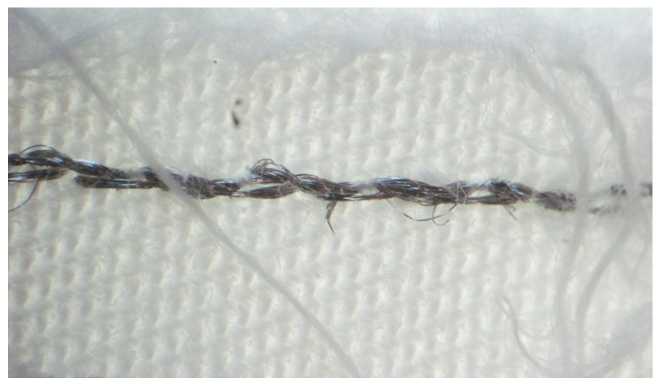
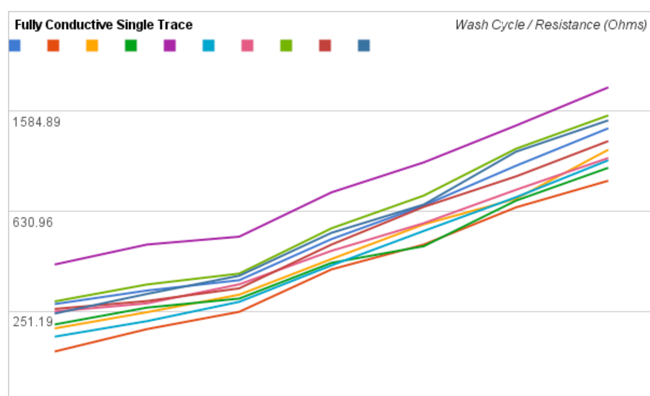
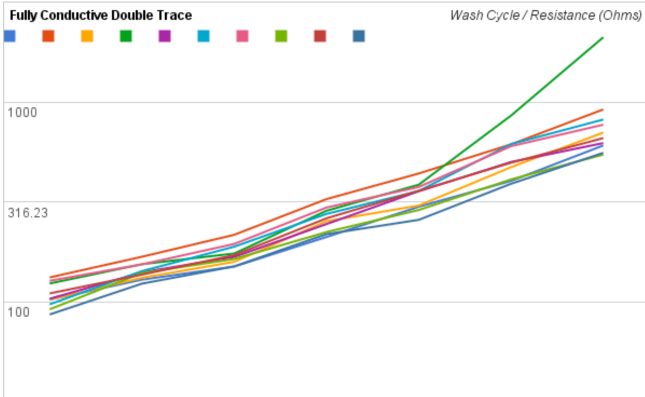


**Figure 8 Swatch B7 more conductive thread double trace**

The double trace further improved the survivability of the thread.




**Graph 6**




**Graph 7**

## Test Condition 8 Fully conductive thread single trace under conductive ink.

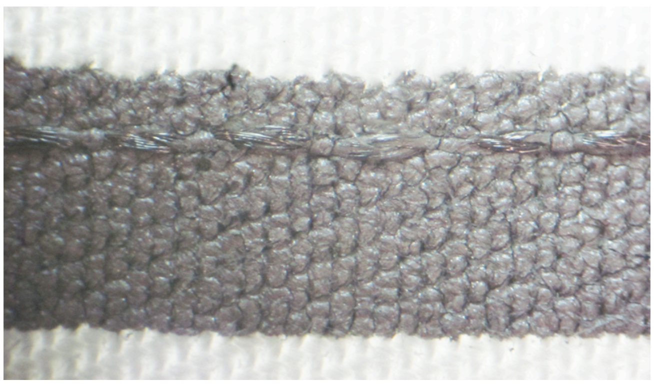
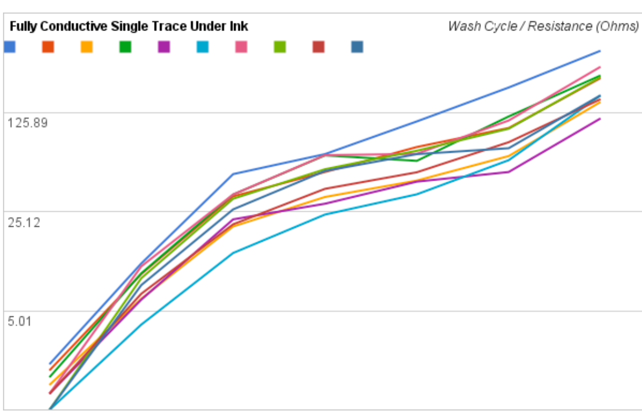



**Figure 9 Swatch B8 more conductive thread single trace under conductive ink**

The conductive ink doesn't fully saturate the fully conductive thread as it did the less conductive thread. However, the ink does fill in the holes punctured in the fabric from the sewing process and adds to the robustness of the trace.

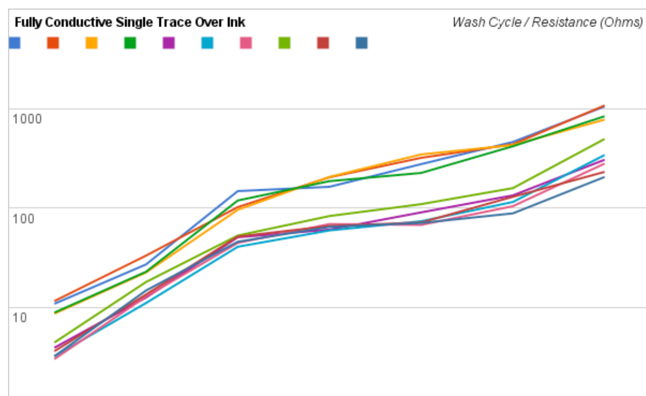



**Graph 8**

## Test Condition 9 Fully conductive thread single trace sewn over conductive ink.


**Figure 10 Swatch B9 more conductive thread single trace over conductive ink**

Again, the thread over the conductive ink does not provide as good a contact and gains resistance faster than being sewn under the print, but not as fast as a trace without printing.




**Graph 9**

## Test Condition 10 Fully conductive thread double trace under conductive ink.

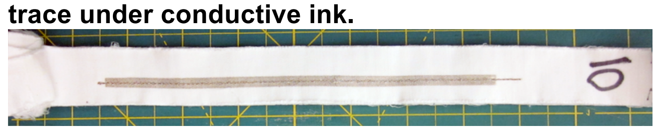
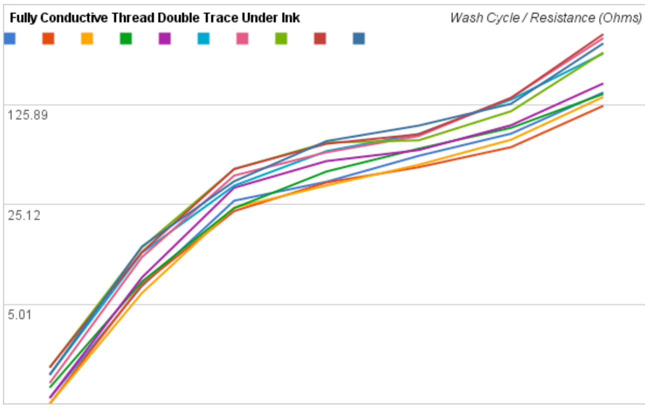



**Figure 11 Swatch B10 more conductive thread double trace under conductive ink**

While both the double trace and single trace of the fully conductive thread under ink survived the wash cycles well, there was surprisingly little difference between the single and double trace in terms of final resistance. Both ranged from 100-400 ohms after the last wash, where they both started between 1-2 ohms.




**Graph 10**

## Test Condition 11 conductive ink.

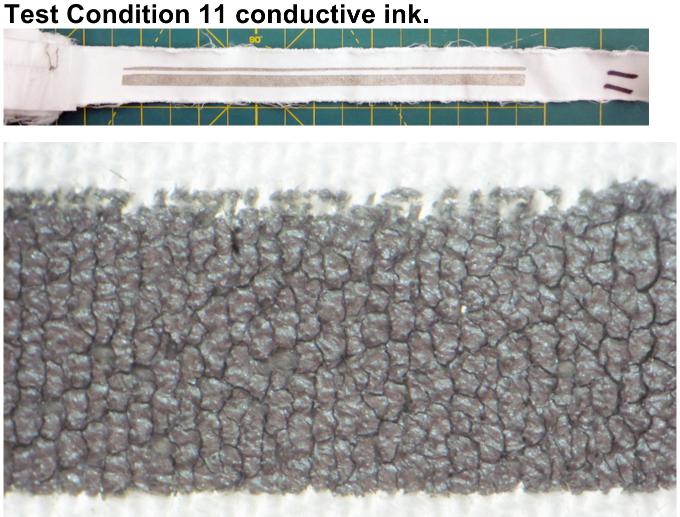
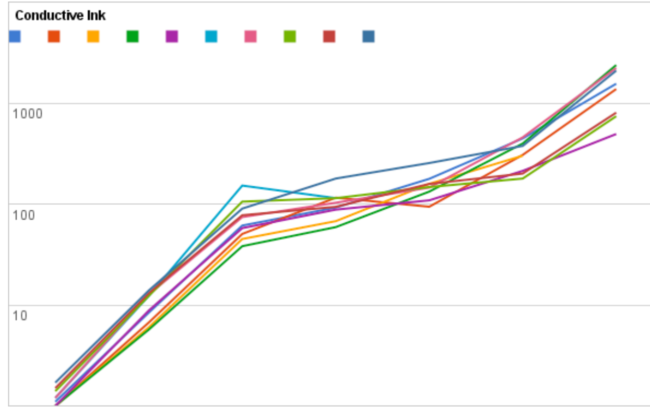


**Figure 12 Swatch B11 conductive ink**

The small cracks in the ink caused the swatch to loose conductivity quite rapidly. Two samples broke completely before completion. These cracks are most likely cause by the swelling and shrinking action of the cotton. When the swatch is bent from the back side of the fabric the cracks can widen and cause the swatch to fail dramatically.




**Graph 11**

## Test Condition 12 conductive ink under plastisol ink.

The plastisol ink performed very well at preventing the conductive ink from being degraded.

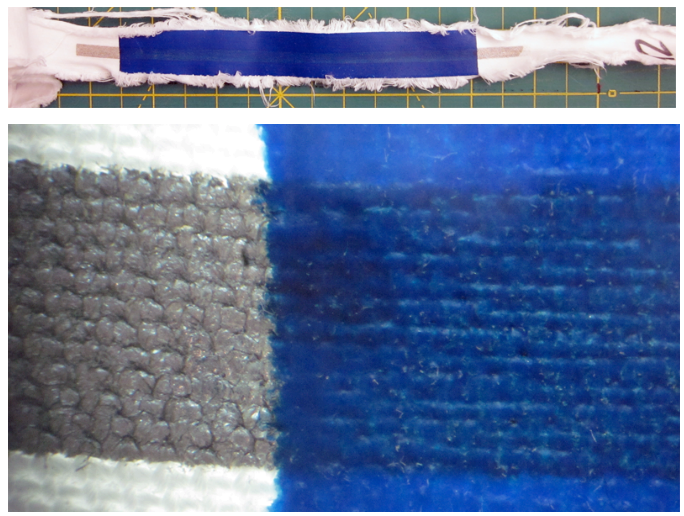
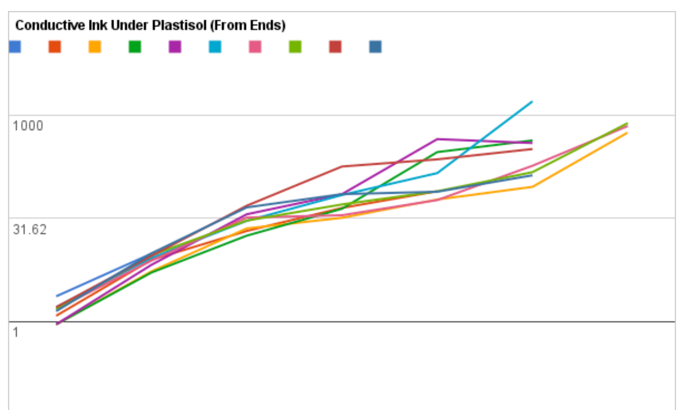
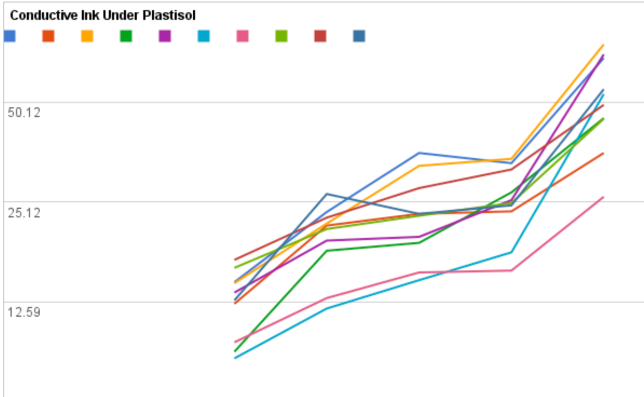


**Figure 13 Swatch B12 conductive ink under plastisol ink**




**Graph 12**

When it became clear that the increase of resistance of the exposed conductive inkpads was increasing significantly faster than that of the ink protected by plastisol, we began measurements at the edges of the plastisol as well as from the ends.




**Graph 13**

Clearly, the plastisol protects the conductive ink and prevents the increase of resistance we find with uncovered conductive ink. In addition, a single or double trace of fully conductive thread coated with conductive ink seems much more robust than other alternatives.

## CONCLUSION & DESIGN RECOMENDATIONS

We realize that there are currently insulated threads on the market that might hold up much better under washing conditions then the threads we chose to test here. However, currently insulated threads can be very difficult to connect with components in a durable way. We chose to test these types of sewing threads because they are widely available and widely used, and connect easily to components.

When designing a wearable system with traces used to carry electricity we suggest using the more conductive thread [6]. If screen-printing the trace we suggest using a more flexible conductive ink such [1] and covering the trace in all areas not needed for capacitive sensing with insulating plastisol ink (see figure 14).

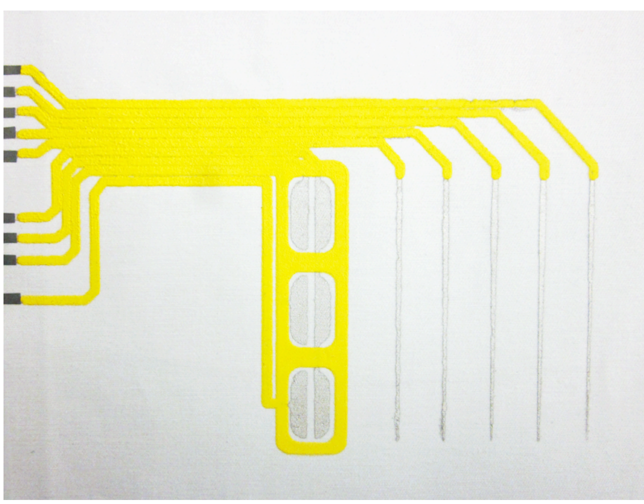


**Figure 14 a screen-printed interface using plastisol ink to insult conductive traces.**

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